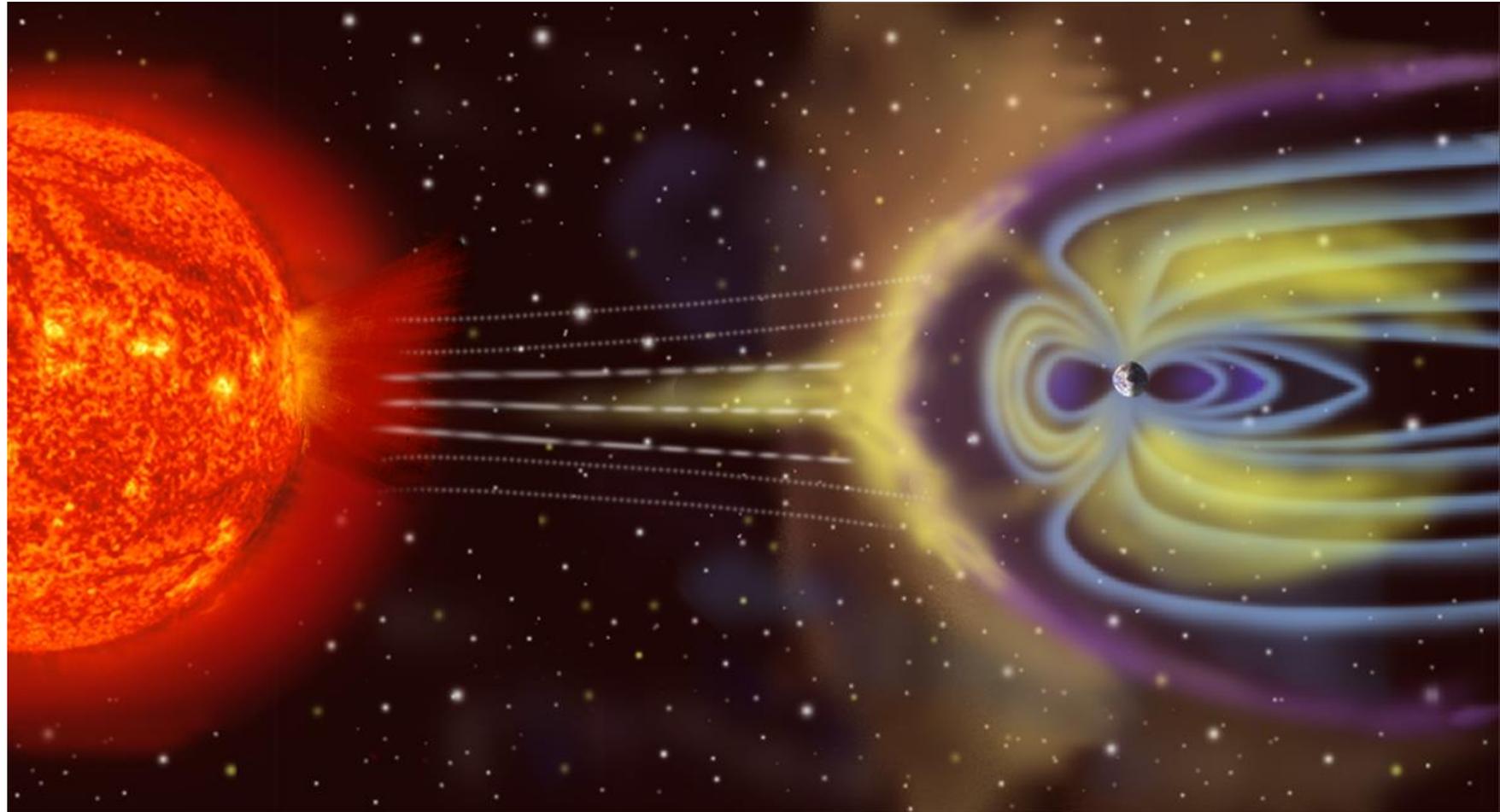


Global Ionospheric Response to CIR/HSS induced geomagnetic storms

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Solar wind – Magnetosphere – Ionosphere coupling

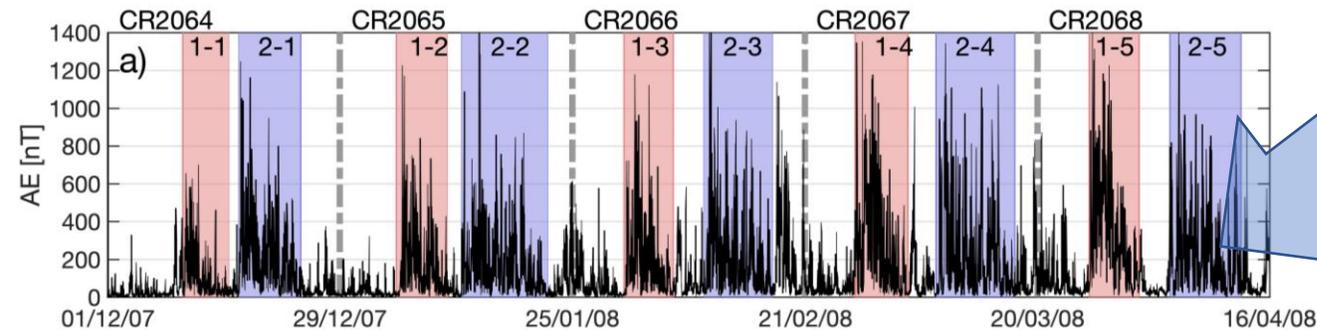
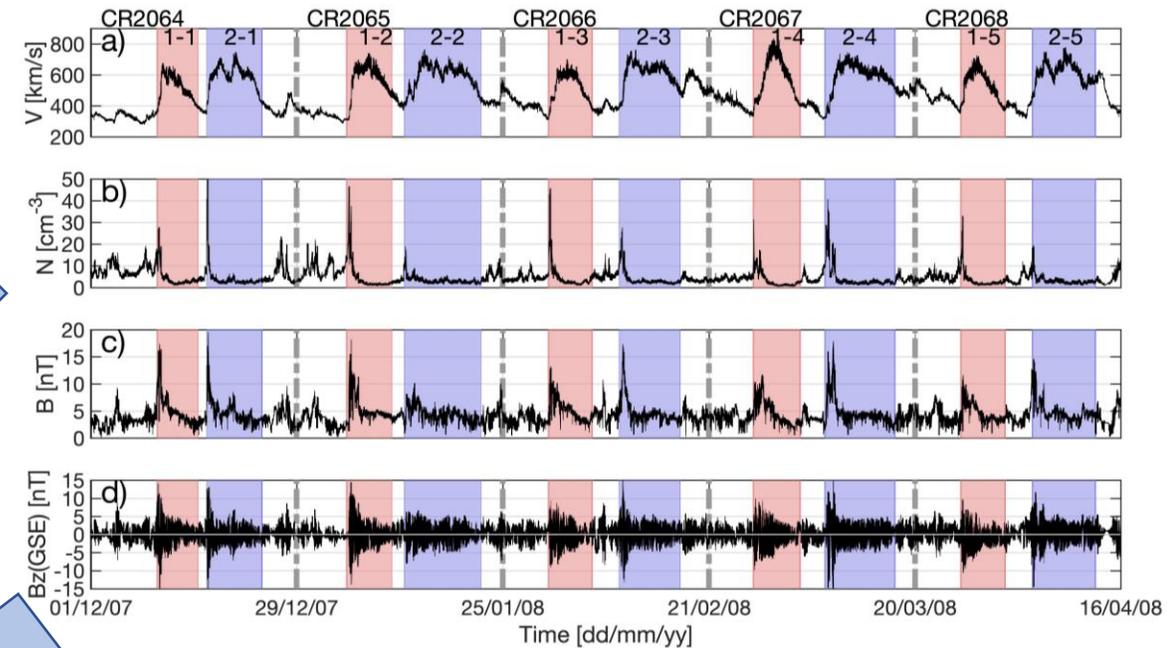
- The topic of the **solar wind -> magnetosphere -> ionosphere coupling** is one of considerable interest, in particular for **space weather** applications.
- While the broad features of this coupling are known, the complexity of the systems involved and of the coupling mechanisms makes it hard to predict or even describe details for individual events.
- In particular, the **small scale ionospheric response** and its geographic variability are an area of active research.
- Here, we investigated **the ionospheric response** to a series of HSS/CIR induced geomagnetic storms, at **different temporal scales**.



Solar wind – Magnetosphere – Ionosphere coupling

HSS / CIRs

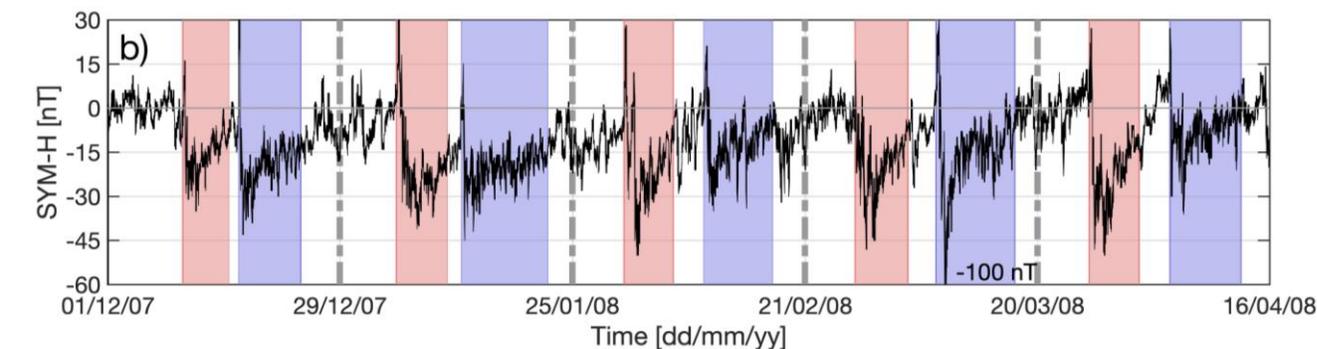
- This analysis focuses on the time interval **December 2007 – April 2008**.
- Several **HSS / CIRs** were observed during this time interval. 
- The events can be grouped into **two categories**, as they were induced by **different coronal holes**.



Geomagnetic Storms

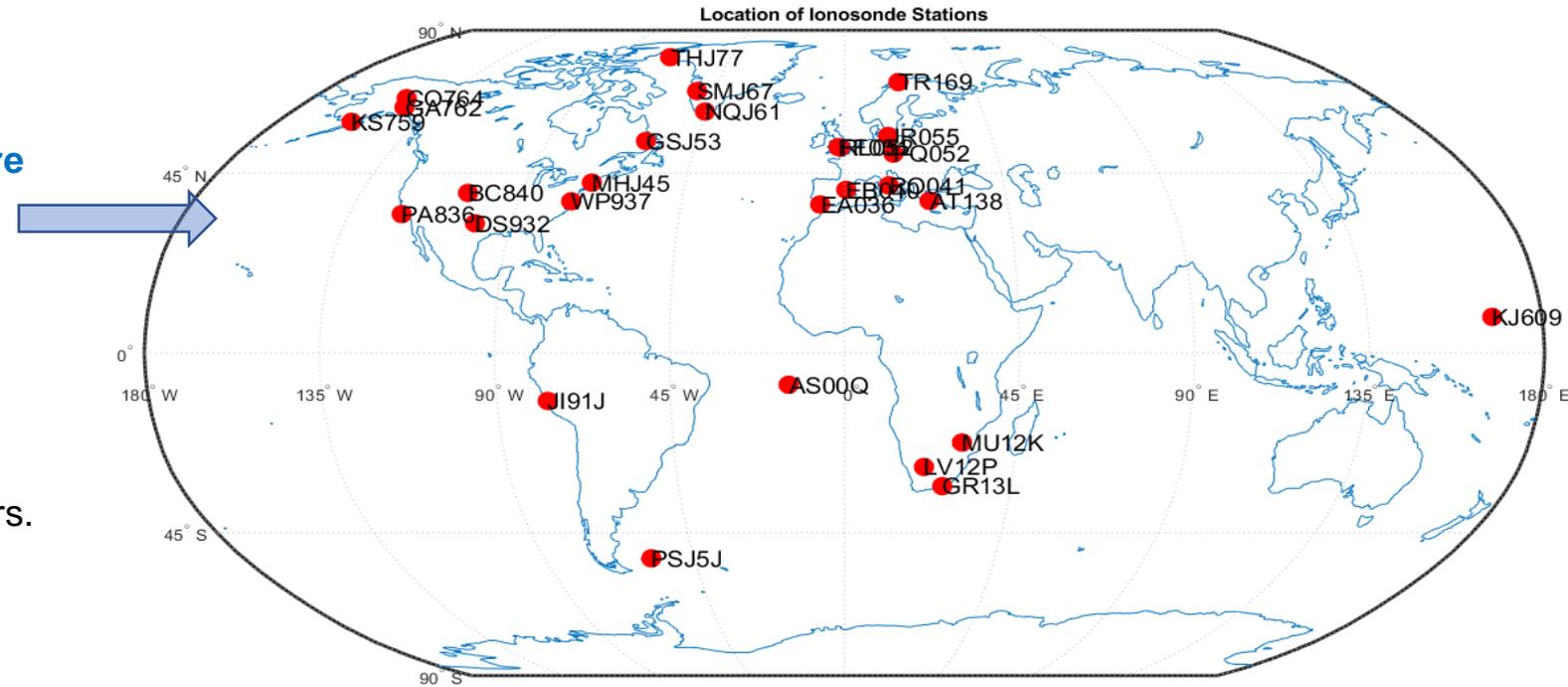
- Each **HSS/CIR** had an associated **geomagnetic storm**.
- The solar wind -> magnetosphere coupling is discussed in more detail by:

Munteanu, C., Hamada, A., Mursula, K. (2019). High-speed solar wind streams in 2007-2008: Turning on the Russell-McPherron effect. Journal of Geophysical Research: Space Physics, 124, <https://doi.org/10.1029/2019JA026846>

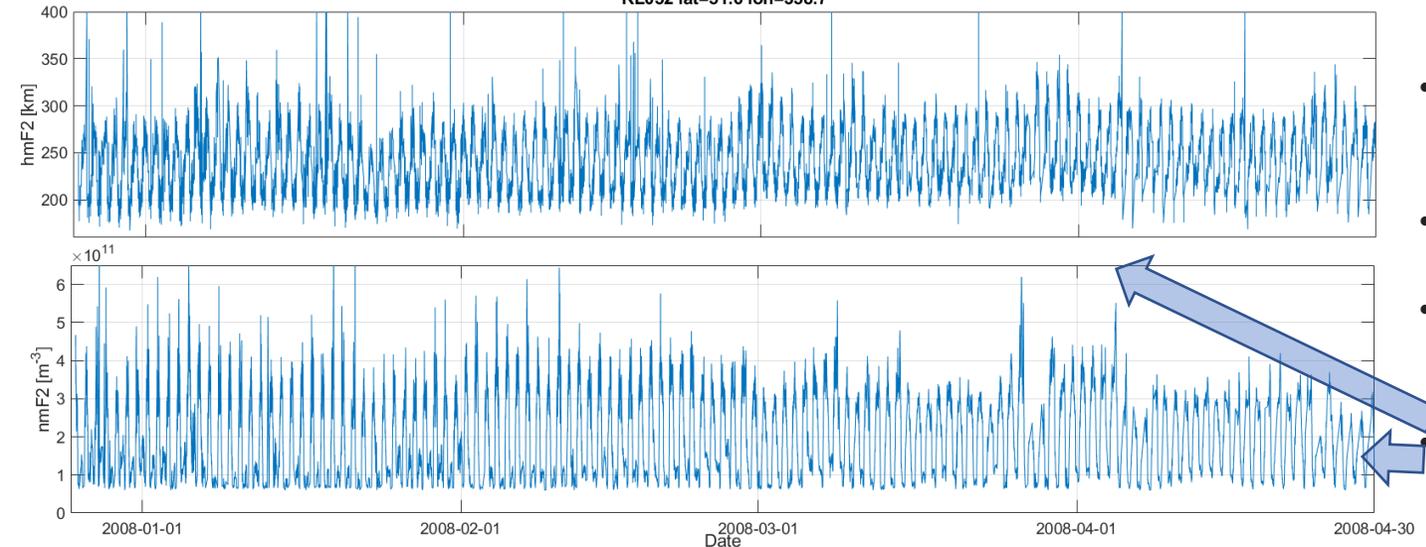


Ionosphere data

- We investigate the **magnetosphere -> ionosphere coupling** using data from 28 globally distributed **ionosonde stations**.
- The data is available through the **NCEI / NOAA** database.
- The geographical distribution of the stations is not perfectly uniform, but it covers most latitude sectors.
- Better coverage over North America and Europe.



RL052 lat=51.6 lon=358.7



- The peak electron density (**$NmF2$**) and its height (**$hmF2$**) are used for this analysis.
- Each station is operated independently.
- The sampling interval can vary, but it is typically 15 minutes.
- Here is an example from a mid-latitude Europe station.

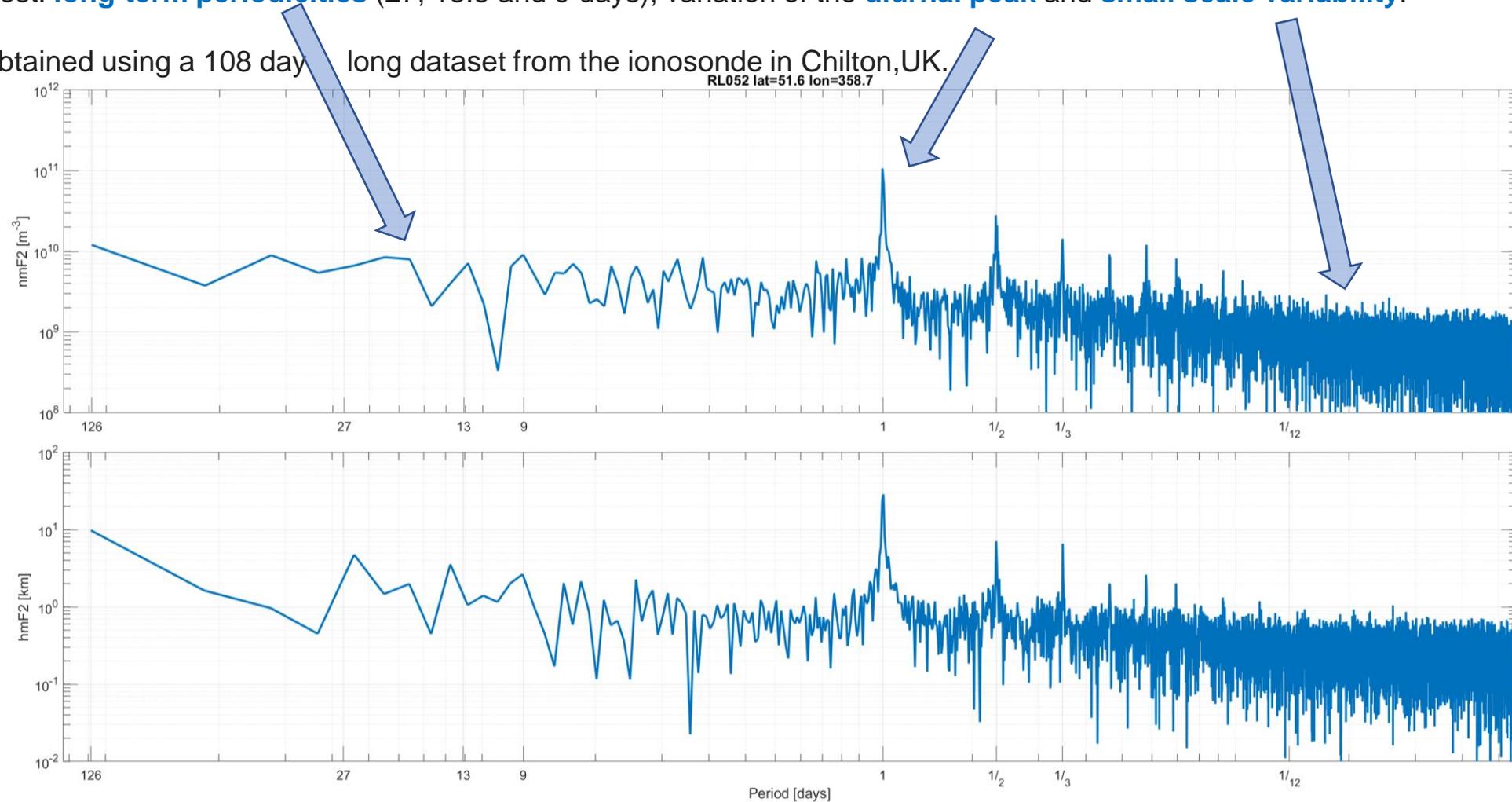
Spectral Analysis

- Using **spectral analysis** tools we can highlight the main features of the **ionospheric response** to the geomagnetic storms.
- Three main effects are of interest: **long-term periodicities** (27, 13.5 and 9 days), variation of the **diurnal peak** and **small scale variability**.

Below is a sample spectrum obtained using a 108 day long dataset from the ionosonde in Chilton, UK.

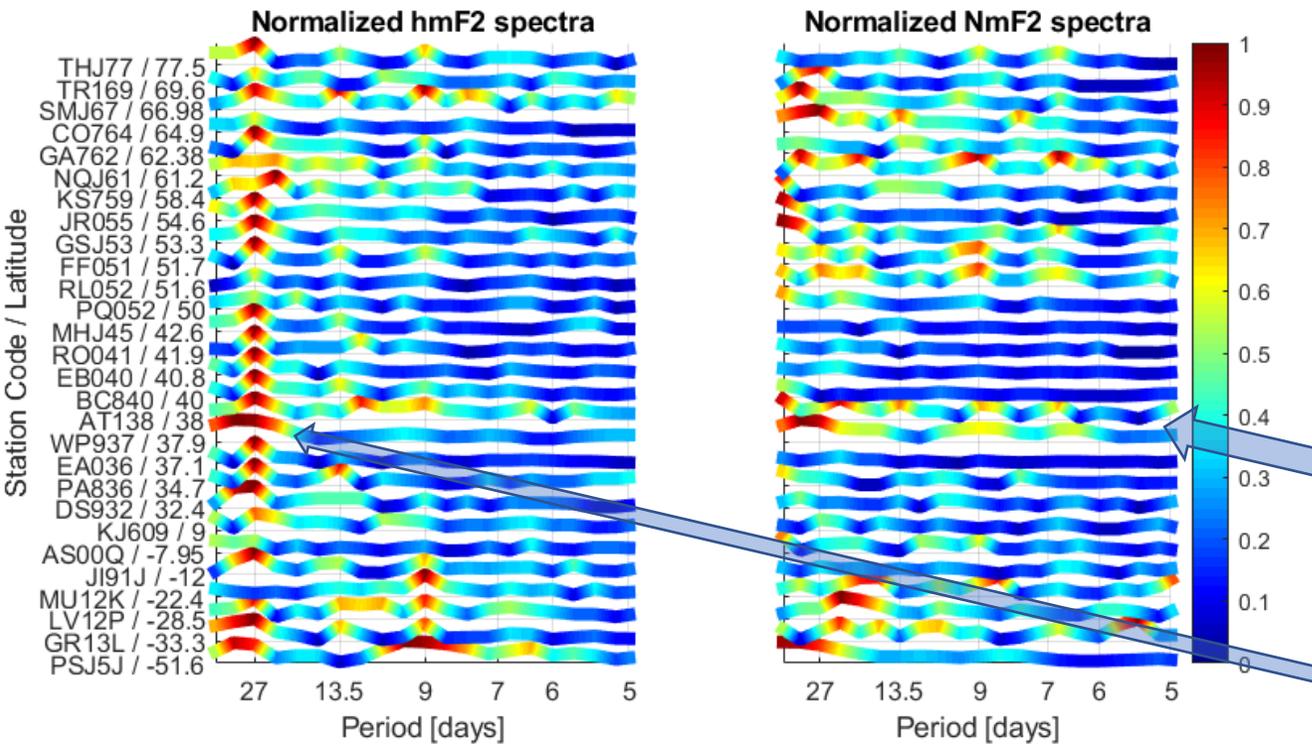
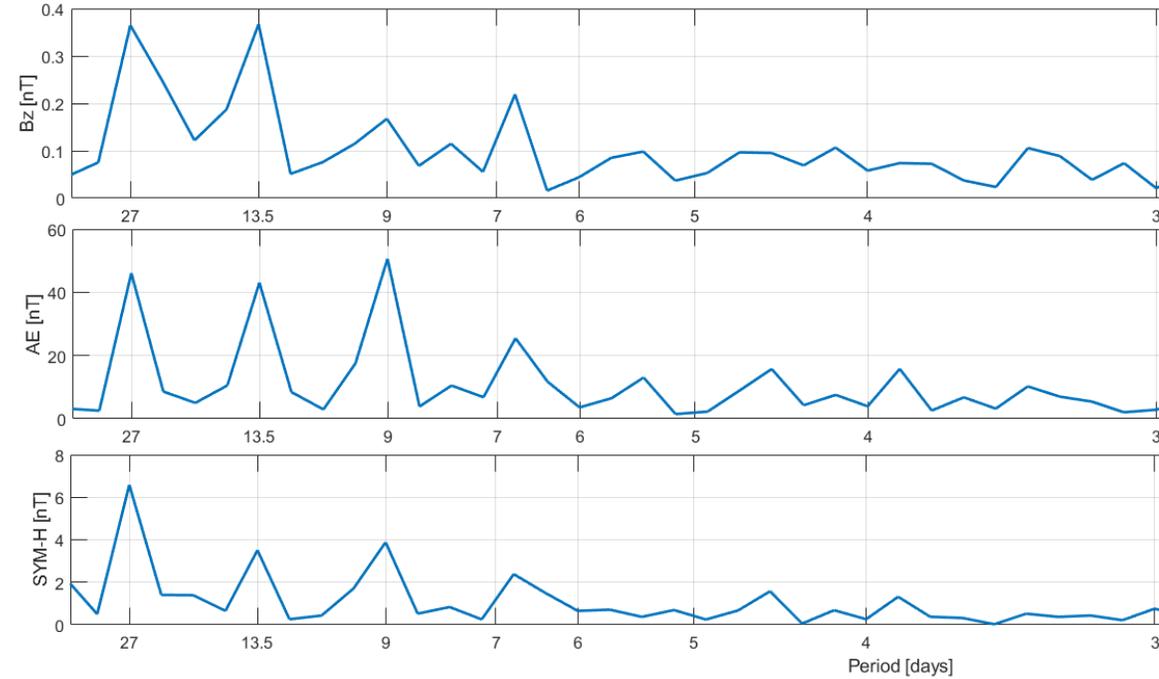
- Note that both the NmF2 and hmF2 spectra show peaks corresponding to periods of 27, 13.5 and 9 days, strong diurnal peaks and small amplitude, high frequency components (likely due to TIDs and other forms of small scale ionospheric variability).

- These require different investigative tools and will be addressed separately.



Long-term periodicities

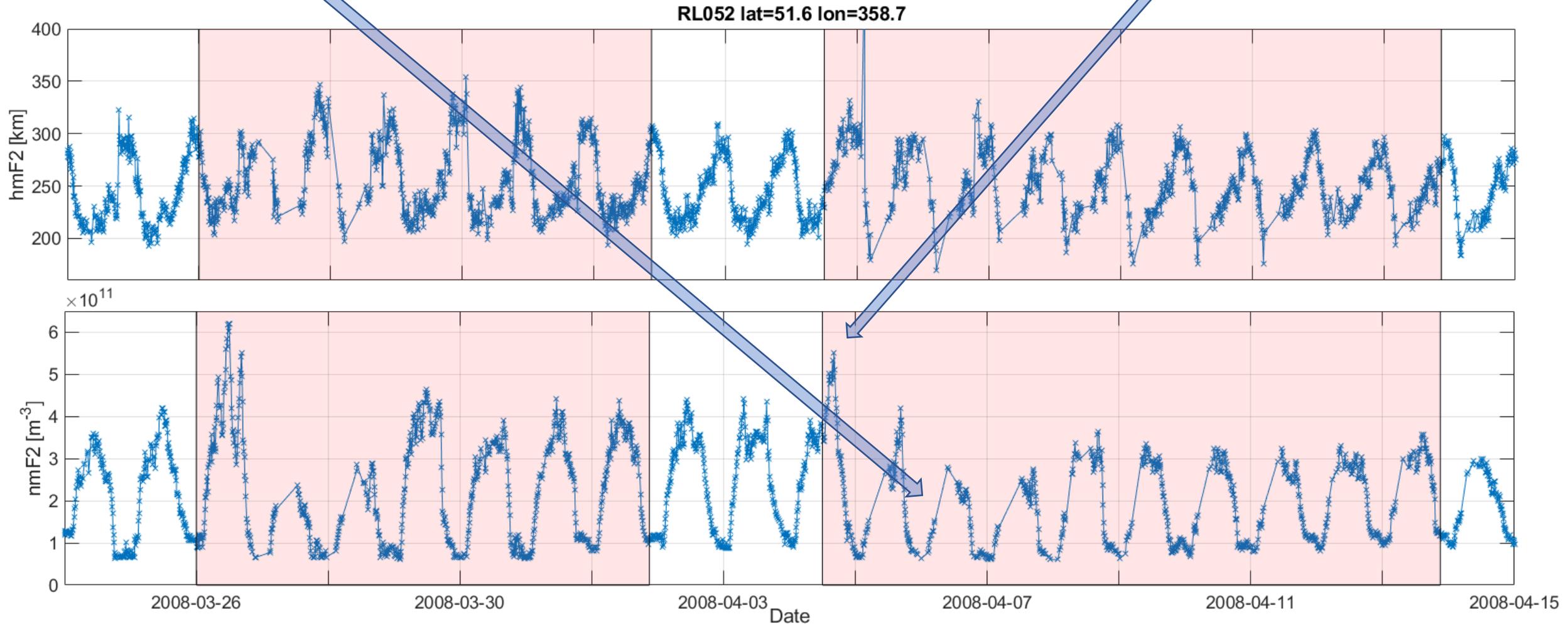
- It is well known that the **solar wind** spectrum contains **periodicities of 27, 13.5 and 9 days**.
- Through the **solar wind -> magnetosphere coupling**, associated periodicities are **imposed on the magnetosphere**, as can be seen in the **geomagnetic indices**.
- Several other, smaller spectral peaks can also be observed.



- The **magnetosphere -> ionosphere coupling** imposes the same **periodicities on the ionosphere**, as can be seen in the NmF2 and hmF2 data.
- In order to highlight the **global ionospheric response**, the low-frequency component of the spectra are independently **normalized to 1**.
- The result shows that the **ionospheric response** can vary significantly in amplitude for NmF2, but it is **very uniform for hmF2**.

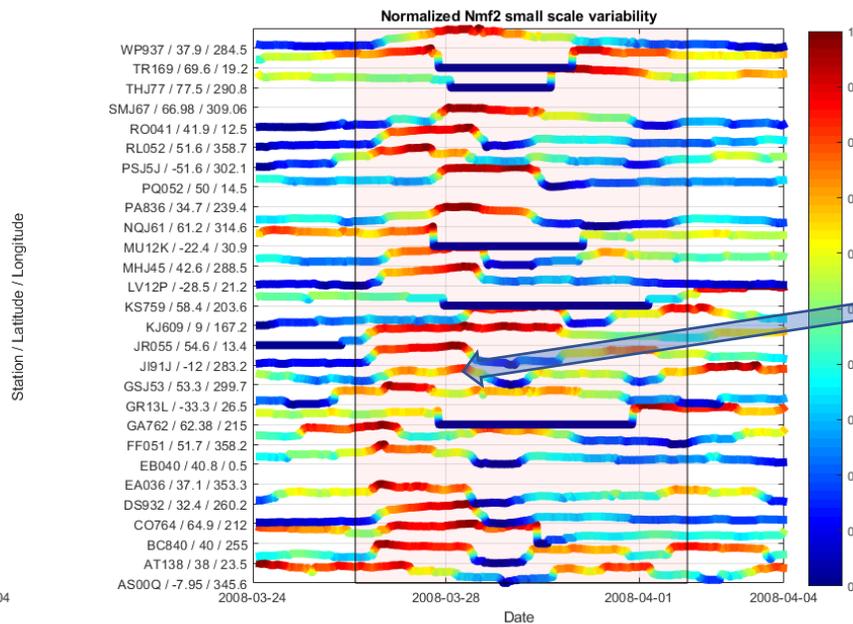
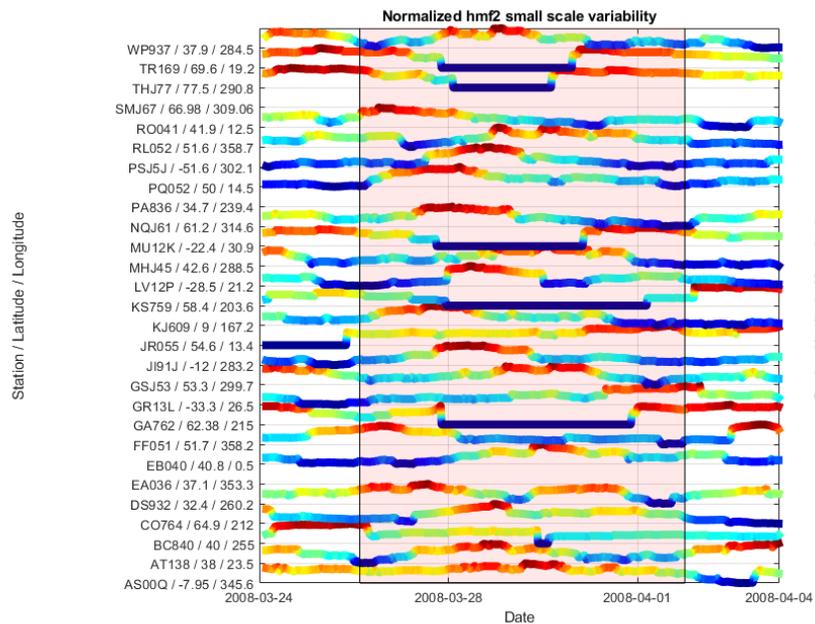
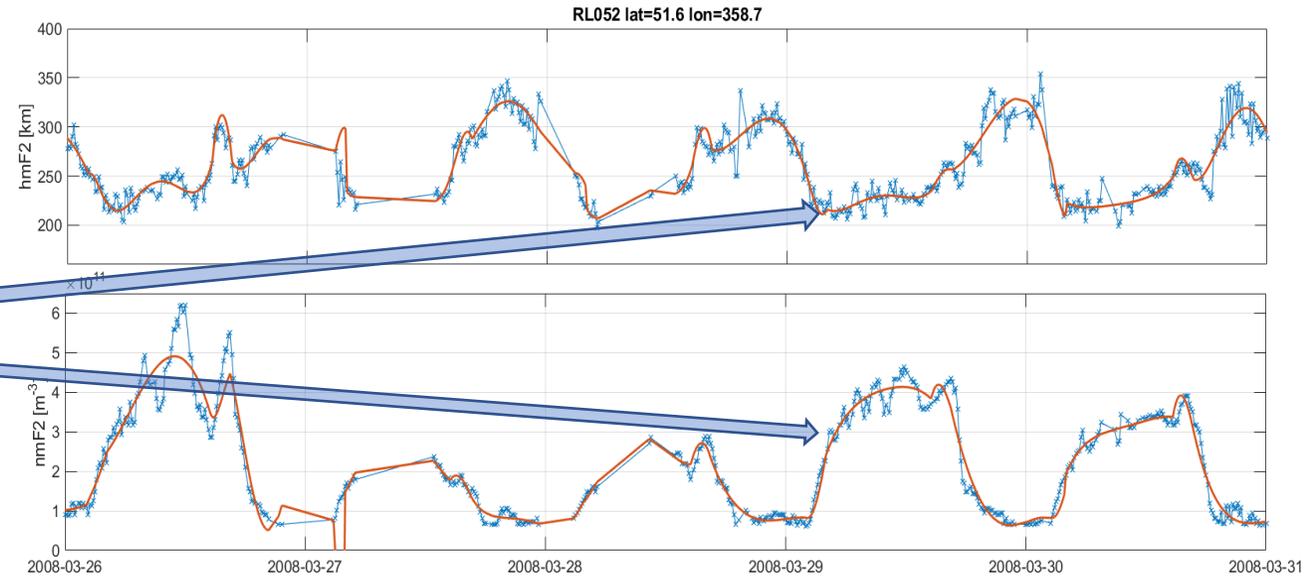
Main Ionospheric impact

- The **main ionospheric impact** of a geomagnetic storm is generally characterized by an increase in NmF2 (**positive phase**), followed by a sharp decrease (**negative phase**). Two examples of such a response are shown here.
- Note that the regularity of these occurrences explain to a large extent the existence the long-term periodicities discussed above.



Small scale variability

- Due to the frequently non-uniform sampling of the data, it is feasible to use standard spectral techniques for the analysis of high-frequency spectral components (periods of tens of minutes to several hours).
- A **detrending** technique is used to remove the dominant diurnal variability, highlighting **small amplitude variations**, likely caused by **AGWs / TIDs** and other sources of small-scale variability.
- The amount of **small-scale variability** can be estimated using the **variance** of the detrending residual. The temporal evolution of this variance is investigated for each station.



- The impact of a single geomagnetic storm is shown here for all stations.
- Note that while the hmF2 response is quite complex, there is a **global increase** in the small scale variability in NmF2 for **1-2 days after the start of the geomagnetic storm**.
- The ionospheric response to each geomagnetic storm is different, but **similar effects** (likely due to increases in levels of **auroral TIDs**) were highlighted for **8 of the 10 storms** during this 108 day interval.

Summary and conclusions

- We investigated the ionospheric impact of a series of HSS / CIRs from December 2007 – April 2008.
 - 10 such events in the solar wind were highlighted by *Munteanu et al. (2019)* to cause a series of geomagnetic storms.
 - We used several data analysis and processing techniques, due to the broad frequency range of the phenomena of interest and the variation in data sampling rate.
- Using Ionosonde data from 28 globally distributed stations, we describe the ionospheric impact of this series of storms.
 - Periodicities of 27, 13.5 and 9 days are highlighted at all latitudes
 - The hmF2 response was much more uniform, although smaller in amplitude than the associated NmF2 response.
 - This periodicity is the result of recurrent structures in the solar wind, rather than a true sinusoidal oscillation.
 - We highlighted a systematic, global increase in small-scale ionospheric variability a few days after the start of the geomagnetic storm.
 - This is likely caused by an increase in AGW / TID activity from auroral sources, due to increased Joule heating and particle precipitation.